



Effect of lumbar support on seating comfort predicted by a whole human body-seat model



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ABSTRACT

Automobile seat greatly affects the ride comfort of drivers in a prolonged driving. Not only the layout parameters of automobile seats, such as seat height, cushion inclination angle, backrest inclination angle, etc, but also the backrest surface related with lumbar support all affect the seating comfort. The human body-seat system includes the three-dimensional data of body based on anatomy and anthropometry, three-dimensional data of seat and adjustable assembly interaction between body and seat based on human body kinematics. Body height and driving posture are adjusted in POSER software, then the solid model of human skin, skeleton and muscle are created in ANSA software, and the integrated model of body-seat system is created in ABAQUS software. The adjustment of the lumbar support parameters is achieved by setting boundary condition of lumbar support region of seats. The finite element model of human body-seat system is validated by comparison to available literature results. At last the finite element model is applied to analyze the effect of lumbar support parameters of seats on the interaction between body and seat under the action of gravity. The pressure value and distribution, contact area, total force of backrest and intervertebral disc stress are obtained. The result shows that the optimal thickness of seat's lumbar support size for the seating comfort is 10 mm after comprehensive comparison and evaluation.

Relevance to industry: This study investigated the effects of lumbar support on seating comfort, and can be used to protect the lumbar health. The modeling and simulation method can be applied for the optimization design of vehicle seats.

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1. Introduction

Nowadays most of working posture in many industries are the sitting posture. Sitting or keeping a certain posture for a long time not only makes people feel uncomfortable but also might cause health problems. For example, frequent immobilized continuous sitting makes the muscle tissues intolerable for further compression (Mohanty and Mahapatra, 2014). So we need to optimize the seat design constantly to improve the seating comfort (Grujicic et al., 2009; Akgunduz et al., 2014). Many experimental investigations (Wu et al., 1999; Park and Kim; Gyi and Porter, 1999; Miliwojevich et al., 2000; Inagaki et al., 2000; Hartung et al., 2004; Mergl, 2006a and 2006b; Vos et al., 2006; Zhang et al., 2007; Kyung and Nussbaum, 2008; Vincent et al., 2012) found

that the contact pressure between seat and human has significant correlation with seating comfort.

Although the experiment and simulation methods can help us study the pressure distribution between human body and seat, the experiment method is more difficult for us to obtain the stress inside the human body (Grujicic et al., 2009; Du et al., 2013). While finite element simulation can not only obtain the characteristics of pressure distribution between human body and seat, but also obtain the shear force of their interfaces and internal stress distribution of human body. Using finite element models of human body and seat to mimic the interaction between human body and seat can help us accelerate the progress of seat design and save time and costs of seat prototypes.

More realistic simulation of pressure distribution depends on accurate modeling of body shape, structure and material characteristics. A lot of approaches have been published for seat comfort studies so far. Mandal (1984, 1987) used physics-based reasoning in place of the traditional empirical and subjective approaches to

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investigate and evaluate the human body in a seated posture. [Makhsous et al. \(2007\)](#) analyzed the effect of the innovative design seat on the pressure distribution between the hips and cushion and the muscle stress of the ischial tuberosity through the established biomechanical model. [Makhsous and Lin \(2009\)](#) established the biomechanical finite element model with muscles and simulated the load of buttock in seated individuals with spinal cord injury. [Grujicic et al. \(2009\)](#) established a finite element model including the seat and human body, and calculated the pressure distribution of the seat cushion on the conditions of supported feet and hanged feet, respectively.

In addition, some more detailed whole-human-body models were also developed and used to investigate the interactions between human body and seats. The AnyBody Modeling System enables creation of a detailed computer model for a human body as well as examination of the influence of different postures and the environment on the internal joint forces and muscle activity ([Damsgaard et al., 2006](#)). [Siefert et al. \(2008\)](#) used a full-body finite element model CASIMIR to analyze the static and dynamic characteristics of occupant seat. The POSER software has the database of human body based on the human anatomy and anthropometry, and the human body size in the database of software reached a very high consistency with actual human body size ([Du et al., 2013](#)), so the size of human body surface, muscle and skeleton inside can be obtained, besides, the posture of human body model can be adjusted based on kinematics of human body.

The aim of this paper is to analyze the effect of different lumbar support thickness on the static seating comfort using the three-dimensional (3D) finite element model of the whole human body-seat system. The main researches of this study include: (a) solving the problem of 3D whole-human-body finite element modeling by applying the POSER, PRO/ENGINEER and ANSA software and validating the whole-human-body model; (b) setting the boundary conditions of the vehicle seat near the human lumbar spine to adjust the lumbar support parameters; (c) applying the finite element model to analyze the effect of different lumbar support parameters on the stress distribution of lumbar intervertebral discs and the force interaction between the human body and the seat.

The 3D whole-human-body finite element model can provide a significant simulation environment for various human body experiments, such as impact test, drop text and vibration test, etc.

2. Modeling of the seat and human body

2.1. The vehicle seat model

Geometry model of the car seat was created in the commercial software PRO/ENGINEER of three-dimensional modeling. The finite element model of car seat includes the metal frame and the cushion, backrest and headrest of polyurethane.

The lumbar support device of the car seat is shown in [Fig. 1\(a\)](#). Fixed plate 3 is fixed to the backrest framework of seat. Adjustment plate 2 can be adjusted along the Z-axis. Support plate 1 can be adjusted along the X-axis. The lumbar support device has two main parameters and they are simply called the support height and the support thickness. The support height is to adjust the support position due to different human height, in case the support position is not correct. For example, the support position is above the lumbar spine or below the lumbar spine, we can adjust it by adjusting the plate 2 along the Z-axis; Support thickness is equal to the magnitude d in the direction of X (perpendicular to the lumbar spine). It can be accomplished by adjusting the lumbar support plate 1 along the X-axis. To mimic different support scales, different support parameters of the lumbar support device are achieved by changing

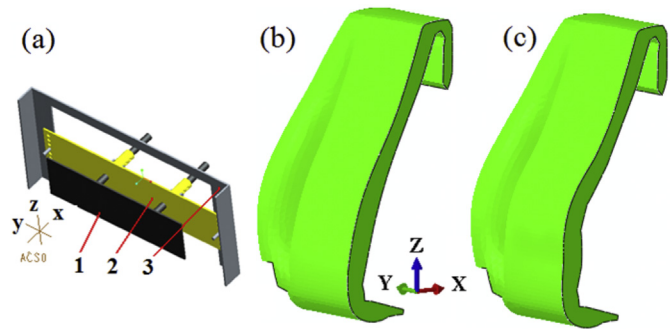


Fig. 1. The seat backrest and the lumbar support device. (a) The lumbar support device (1- Lumbar support plate, 2- Adjusting plate, 3- Fixed plate), (b) The seat backrest shape for the support parameter d_1 , (c) The seat backrest shape for the support parameter d_3 .

the boundary conditions of backrest near lumbar spine. The boundary conditions of the model with different support parameters are shown in [Table 1](#). The four kinds of support conditions are corresponding to the following support magnitudes d_1 , d_2 , d_3 and d_4 , and set $d_1 = 0$ mm for no support, $d_2 = 10$ mm for small support, $d_3 = 20$ mm for middle support and $d_4 = 30$ mm for large support, respectively. The results of support effects of different support parameters are shown in [Fig. 1\(b\)](#) and (c).

Different types of elements have a great influence on the accuracy of calculating results. [Markert \(2008\)](#) used different types of elements (such as the first-order tetrahedral element T4P4B, the second-order tetrahedral element T10P4 and Hexahedron element H20P8 etc) to compare and analyze the deformation of polyurethane cushion under the action of pressure. The results showed that the difference between the deformation calculated by the second-order tetrahedral element and the deformation calculated by the hexahedron element is small, but the deformation calculated by the first-order tetrahedral element is quite different with the deformation calculated by the hexahedron element for the small-size structure of cushion. Therefore, in order to meet the accuracy requirements, the second-order tetrahedral element is used for the seat cushion, backrest and headrest in this study.

The material of automobile seat backrest is usually polyurethane foam. The main characteristics of polyurethane foam under static pressure loads are determined according to the relevant test standards ([ISO 3386-1, 1986](#)). This test is completed by uniaxial compression in the hydraulic test station. The characteristics of the foam material of backrest are described with the hyper-elasticity criterion in the software ABAQUS. The hyperelasticity of material is described with strain potential energy U , and the function of strain potential energy is as follows.

$$U = \sum_{i=1}^N \frac{2\mu_i}{\alpha_i^2} \left[\hat{\lambda}_1^{\alpha_i} + \hat{\lambda}_2^{\alpha_i} + \hat{\lambda}_3^{\alpha_i} - 3 + \frac{1}{\beta_i} \left((J^{el})^{-\alpha_i \beta_i} - 1 \right) \right] \quad (1)$$

The strain potential energy U is defined by the following parameters. μ_i is the coefficient of initial shear modulus, α_i is the standard material parameter, β_i is the coefficient for degree of compressibility, λ_1 , λ_2 and λ_3 are the principal stretches, J^{el} is the

Table 1
Support parameters and the magnitude of support.

	d_1	d_2	d_3	d_4
x (mm)	0	−9.3	−18.7	−28.0
z (mm)	0	3.6	7.2	10.8
The thickness of the support (mm)	0	10	20	30

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